

Air Pollution and Respiratory Symptoms: Results from Three Panel Studies in Bangkok, Thailand

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Several studies in North American cities have reported associations between air pollution and respiratory symptoms. Replicating these studies in cities with very different population and weather characteristics is a useful way of addressing uncertainties and strengthening inferences of causality. To this end we examined the responses of three different panels to particulate matter (PM) air pollution in Bangkok, Thailand, a tropical city characterized by a very warm and humid climate. Panels of schoolchildren, nurses, and adults were asked to report daily upper and lower respiratory symptoms for 3 months. Concentrations of daily PM₁₀ (PM with a mass median aerodynamic diameter less than 10 µm) and PM_{2.5} (airborne particles with aerodynamic diameters less than 2.5 µm) were collected at two sites. Generally, associations were found between these pollution metrics and the daily occurrence of both upper and lower respiratory symptoms in each of the panels. For example, an interquartile increase of 45 µg/m³ in PM₁₀ was associated with about a 50% increase in lower respiratory symptoms in the panel of highly exposed adults, about 30% in the children, and about 15% in the nurses. These estimates were not appreciably altered by changes in the specification of weather variables, stratification by temperature, or inclusion of individual characteristics in the models; however, time trends in the data cause some uncertainty about the magnitude of the effect of PM on respiratory symptoms. These pollutants were also associated with the first day of a symptom episode in both adult panels but not in children. The estimated odds ratios are generally consistent with and slightly higher than the findings of previous studies conducted in the United States. **Key words:** air pollution, Bangkok, daily diary, particulate matter, respiratory symptoms. — *Environ Health Perspect* 109(suppl 3):381–387 (2001). <http://ehpnet1.niehs.nih.gov/docs/2001/suppl-3/381-387vichit-vadakan/abstract.html>

Epidemiologic research has consistently demonstrated that current levels of public exposure to airborne particulate matter (PM) in North American and Western European cities are associated with a range of health outcomes (1–3). These health outcomes include premature mortality and several types of respiratory-related morbidity, including hospitalization, aggravation of asthma, and acute respiratory symptoms. Although high concentrations of PM are commonly measured in many non-Western cities, any related health effects in these areas are not well documented. Differences in underlying health status, smoking habits, activity patterns, use of medical care, socioeconomic factors, and genetics could produce dramatically different associations between air pollution and health, and thus the degree to which research findings from the Western industrialized nations can be extrapolated to other countries cannot be determined without conducting similar studies in many different locations. In addition, replicating existing research findings in locations with different sets of population and weather characteristics is a useful way of addressing uncertainties about the original studies. For example, daily mortality studies in Santiago, Chile, and Bangkok, Thailand, are consistent with the findings of studies

undertaken in the West in terms of estimated relative risks for PM (4,5). If the original study findings are replicated, despite many differences between study locations and populations, it adds weight to the argument for causality between PM and health effects. To this end, we conducted three prospective panel studies in Bangkok to assess the relationship between daily fluctuations in PM concentrations [measured primarily as PM₁₀ (PM with a mass median aerodynamic diameter less than 10 µm)] and daily frequencies of respiratory symptoms. To date, few studies have examined respiratory symptoms in nonasthmatic children using panel data.

A significant benefit of these panel study designs is that individual characteristics and behaviors that might confound the observed relationship between pollution exposure and health symptoms can be identified and controlled for when analyzing the data. In addition, because the health history, exposure patterns, and lifestyle of a subject generally remain unchanged during the study period, each individual serves as his or her own control, thus eliminating the need for a separate control group. Other important benefits of conducting a symptom diary study include *a*) direct control over the health data collection process so that the needed data are

recorded as desired, with as much accuracy as possible; *b*) flexibility to match the study population and air pollution monitoring locations for the exposure assessment portion of the analysis; *c*) ability to target selected population groups that may have specific characteristics of interest; and *d*) ability to obtain otherwise unavailable data from individual subjects, e.g., detailed health history, smoking history and exposure, socioeconomic characteristics, and behavior and activity patterns, which may be relevant for assessing air pollutant exposure.

Study Populations

Bangkok is situated in a relatively flat plain and has a population of approximately 10 million. Because of its low proportion of roads to surface area, the city has difficulty supporting the large number of automobiles (approximately 4 million) and motorcycles (close to 2 million, many of them with two-stroke engines) operating on the streets in Bangkok (6). The inefficiency of the two-stroke engines and the ubiquitous traffic jams result in a large share of PM₁₀ in Bangkok coming from incomplete combustion of fossil fuels in transportation.

The Pollution Control Department (PCD) within the Ministry of Science, Technology and Environment was operating four monitoring stations for PM₁₀ (beta attenuators) in 1995 when we began our study. The population groups for this study were specifically selected because they lived and worked near one of the PM₁₀ stationary monitoring locations. These PM₁₀ measurements are likely to be better indicators of PM₁₀ exposure for these subjects than they

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might be for subjects who spend time commuting to and working in other locations during the day. We chose three panels located near two of the monitors, at Odean Circle and at Chulalongkorn Hospital. The Odean Circle area, known as the Chinatown of Bangkok, is a densely populated residential and commercial area with small streetside shops located on intertwining narrow roads. Business dealings, which may begin as early as 4 AM and extend beyond 9 PM, usually take place on the ground floor, and the upper floors are used as residences. As a center for wholesale business, Odean Circle is congested with vehicles for a large part of the day. Therefore, the residents in this area are likely to be exposed to high concentrations of air pollution. The Chulalongkorn site is located near the city center and is surrounded by wide streets often congested throughout the day.

The three groups of subjects recruited were adults who lived and worked in the Odean Circle area, children who lived and attended school in the Odean Circle area, and nurses and student nurses at Chulalongkorn Hospital who lived in nurses' dormitories near the hospital. A preselection interview was conducted to identify potential adult subjects in the Odean Circle area with the following criteria: *a*) they lived and spent most of the day within 2 km of the air monitoring station; *b*) they did not smoke; *c*) their main work area or daytime living space was not air conditioned; and *d*) their work area did not have obvious or dominating indoor air pollution sources (e.g., motorcycle repair). Ninety-two people who met the above criteria agreed to participate in the study. We expected this panel would have a relatively high exposure to air pollution.

The nurse group was selected because we expected they would provide high compliance and accuracy of reporting because of their training in the health field. We expected them to have lower air pollution exposures than the adults in the Odean Circle panel as a result of working at least some of the time in air-conditioned areas of the hospital. However, to ensure the nurses chosen for this study did not spend all their indoor time in air-conditioned environments, only nurses who lived in the first five floors of the dormitories without air conditioning were recruited. In addition, to be included in the study, nurses had to be nonsmokers and had to remain in Bangkok on most days off from work. Sixty nurses and 20 fourth-year student nurses who met the criteria agreed to participate.

Children were included because they may have different exposure (e.g., spending more time outdoors) and different sensitivity to air pollution. A preselection questionnaire was sent home with the third- to fifth-grade students who attended the only public school

(Wat Thrimit) in the Odean Circle area. Those who met the specific criteria of living within the Odean Circle area and having parental consent were selected. Consequently, 79 children ranging in age from 8 to 12 years participated in the study.

All subjects (and parents of the children) consented in writing to participate in the study after being informed about what their participation entailed. The adult subjects started their symptom diaries as they were recruited from mid-December 1995 to early January 1996. The children started their diaries on January 9, 1996. The adults were asked to participate over a 90-day period, whereas the children, because of school holidays, were involved for 69 days. The selected subjects were also offered a small monetary incentive paid at the completion of the diary period. Three instruments were developed for the diary study: a subject screening questionnaire for adult subjects, a daily symptom diary form for the adult participants and a simplified version for the children, and a background questionnaire for all study participants. All of the diary work was conducted in Thai. Survey instruments from many previous studies were used as a starting point for the development of these symptom diary instruments, but careful translation was needed to ensure they were easy to understand and use by the local study sample.

In the Odean Circle area, field staff interviewers visited each adult subject daily and recorded responses to the diary questions. This was necessary to maintain reasonable response rates and compliance for this panel. The nurses completed the diaries on their own, with weekly contacts from selected nurses recruited to help supervise the diary execution and periodic contacts from the study team. Schoolchildren completed the diaries at school with the supervision and assistance of their teachers. They took the diaries home on weekends and holidays and were encouraged to fill them out on their own. Diaries were completed regarding symptoms on the previous day. Up to 2-day recall was allowed if a day was missed for any reason.

Data and Methods

Symptoms reported from the daily diary were grouped into three major categories: *a*) any respiratory symptom; *b*) upper respiratory symptom (i.e., nasal congestion, sore throat, or cold); and *c*) lower respiratory symptom (i.e., cough, phlegm, wheeze, chest tightness, or shortness of breath). In addition, as a sensitivity analysis, we examined lower respiratory symptoms without including cough.

Daily curbside readings of PM₁₀ were obtained from PCD's beta-gauge monitors located at Odean Circle and Chulalongkorn

Hospital. In addition, for a limited number of days, dichotomous samplers collecting PM_{2.5} (airborne particles with aerodynamic diameters less than 2.5 µm) and PM₁₀ were located at each of the curbside sites. With the data from these monitors, we could check the correlation of daily PM₁₀ across the two locations, the correlation of daily PM₁₀ to daily PM_{2.5}, and the ratio of daily PM_{2.5} to daily PM₁₀. Daily meteorologic data, including temperature, humidity, dewpoint, and precipitation, were obtained at the Bangkok metropolitan weather station at Queen Sirikit Convention Center near downtown. Logistic regression analysis was used to examine the relationship between subjects reporting upper or lower respiratory symptoms on any given day and PM₁₀. Other factors that change on a daily basis (e.g., temperature, humidity, day of week) and individual characteristics (e.g., age, gender, education) were also examined in the analysis. The data were analyzed separately for each of the three subject groups because they were likely to be heterogeneous with regard to exposure, time activity, susceptibility, and smoking exposure.

Previous air pollution studies have indicated the onset of many of the health outcomes is associated with temperature and humidity. As the actual response time to these factors is uncertain, contemporaneous values and 1-, 2-, and 3-day lags of the meteorologic variables were examined. A parsimonious model was obtained based on the associated *t*-statistics of the candidate variables. Once the best regression model for factors other than air pollution was obtained, PM₁₀ was then entered into the model. Single-day concentrations lagged up to 3 days and moving averages of up to 4 days were considered.

Additional sensitivity analysis was conducted to determine how robust the results were to regression specification. First, the model was run with and without meteorologic variables. Second, a variable indicating whether a subject had a symptom on the previous day was added to the model, because a given symptom episode may last several days. Next, the data were stratified after omitting the hottest 25% of the days and then the coldest 25% of the days. These models were run to investigate whether temperature extremes were confounding the observed effect of PM₁₀ on symptom incidence. Fixed-effects models were also estimated to account for the repeated observations nature of the panel data and to assess the effect this might have on the results. Fixed-effects models allow the baseline symptom incidence to vary for each individual, so this is an alternative approach to account for differences across individuals.

Models were then run using a loess smooth for both day of study and daily temperature. These smoothers are data driven

and represent the underlying pattern of symptoms over time and temperature. The loess smoothing technique can accommodate nonlinear and nonmonotonic patterns between time (or temperature) and the health outcome, offering a flexible nonparametric modeling tool. In the loess smooth, each observed value is replaced by a predicted value, generated by a weighted regression of values in a specified neighborhood (span) around the value (7,8). Greater weight is given to observations close to the middle of the chosen span. This predicted value is the smoothed estimate of the data point, and the method is repeated over all observations. In this manner, the underlying pattern of daily symptoms over time is empirically determined, and this function can then be added to the model as a control variable. We chose a span based on the Akaike Information Criteria, which balances the bias and variance incurred by the smoothing approach (7). The optimal span was approximately 30% of the data, or roughly 1 month for each of the morbidity end points. However, the regression results were generally insensitive to the chosen span.

Finally, the effects of PM_{10} on the likelihood of a new symptom (as opposed to the probability of any day with a symptom) were examined. A new symptom data set for each individual for each symptom category included only those days that followed a day with no symptom in that category for that individual. This is an effective manner to examine a model where serial correlation is minimized.

Results

Table 1 summarizes the following characteristics of the diary subjects at the three sites: age, sex, existence of chronic conditions, household smoking status, availability of air conditioning, and use of charcoal in the home. A total of 265 subjects participated in the study. Completion rates were quite high, with only nine subjects completing fewer than 30 days of diaries and five subjects not completing the background questionnaire. (These subjects were dropped from further analysis.) The average number of days completed by the remaining 251 subjects was about 90 for the adult and nurse samples and about 70 for the schoolchildren. (A school holiday cut short the study period for the schoolchildren.) The average daily completion rates for the three groups were as follows: Odean adults, 95%; schoolchildren, 99%; and nurses, 99.9%. These completion rates are very high, showing excellent compliance by each of the groups.

Table 1 also summarizes information about the average daily incidence of reported symptoms during the diary period. For example, the average daily incidences of lower

Table 1. Characteristics of diary subjects.

Characteristic	Odean Circle adults (<i>n</i> = 92)	Nurses (<i>n</i> = 80)	Children (<i>n</i> = 79)
Sex	24% male	All female	40% male
Age (number of subjects)	20–30 (24) 31–40 (32) 41–50 (18) 51–60 (19) Over 60 (9)	20–30 (32) 31–40 (25) 41–50 (12) 51–60 (11)	8–12
Average daily incidence of upper respiratory symptom	24%	53%	32%
Average daily incidence of lower respiratory symptom	25%	59%	40%
Currently have a chronic respiratory condition	13%	24%	29%
Other member(s) of household smokes	49%	None	57%
No air conditioning in the home	76%	100%	76%
Use charcoal in the home for cooking, at least sometimes	18%	None	9%

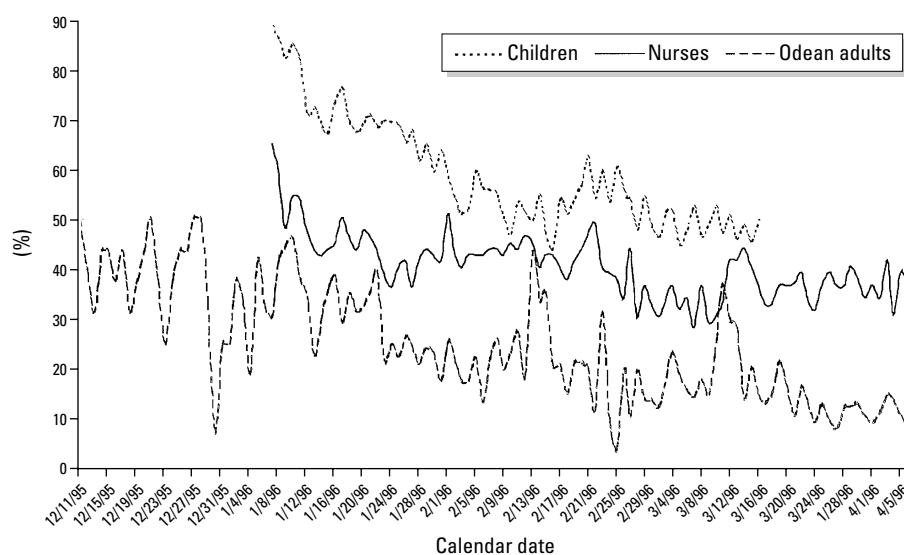


Figure 1. Average daily incidence of reported lower respiratory symptom.

Table 2. Descriptive statistics for daily air pollution and meteorologic data.

Measurement	Mean	Range
PM_{10} , Chulalongkorn Hospital, curbside beta-gauge ($\mu g/m^3$)	83	40–213
PM_{10} , Odean Circle, curbside beta-gauge ($\mu g/m^3$)	104	56–242
$PM_{2.5}$, Chulalongkorn Hospital, curbside dichotomous ($\mu g/m^3$)	51	12–122
$PM_{2.5}$, Odean Circle, curbside dichotomous ($\mu g/m^3$)	56	19–118
Daily average temperature ($^{\circ}C$)	28	22–32
Daily average humidity (%)	65	42–85

respiratory symptoms were 25, 59, and 40%, respectively, for Odean adults, schoolchildren, and nurses in the study. Rates of reported symptoms were high relative to similar studies conducted in the United States, as was the reported prevalence of chronic respiratory conditions. The most commonly reported symptoms for all three groups were cough, phlegm, nasal congestion, and sore throat. The daily proportion of subjects reporting upper and lower respiratory symptoms was correlated across the three groups, with correlation coefficients at or above 0.6 (Figure 1), suggesting similar environmental factors might be affecting all three groups.

Table 2 details the PM and weather data. The mean curbside readings of PM_{10} (24-hr

averages) at Odean Circle and Chulalongkorn were 104 and 83 $\mu g/m^3$, respectively, with some readings above 200 $\mu g/m^3$. $PM_{2.5}$ concentrations at the two sites averaged 56 and 51 $\mu g/m^3$, respectively. This indicates $PM_{2.5}$ to PM_{10} ratios of about 50%. Daily PM_{10} concentrations were highly correlated with daily $PM_{2.5}$ at both sites ($r = 0.85$ and 0.92 , respectively, at Odean Circle and Chulalongkorn). Because the number of days with $PM_{2.5}$ data was substantially less than for PM_{10} , the analysis reported here focuses primarily on the PM_{10} data. However, the high correlation between $PM_{2.5}$ and PM_{10} on the days when both were measured suggests $PM_{2.5}$ could be a causative factor behind any observed PM_{10} effect.

The daily PM₁₀ concentrations at Chulalongkorn were highly correlated with those at Odean Circle ($r = 0.95$). This correlation suggests the curbside measurements are reflecting the general day-to-day fluctuations in PM₁₀ concentrations over a reasonably wide area in the city, because these locations were a few miles apart. PM₁₀ concentrations at both sites were moderately inversely correlated with daily temperature ($r = -0.38$ and $r = -0.32$, respectively) and humidity ($r = -0.55$ and $r = -0.47$, respectively), at Odean Circle and Chulalongkorn.

Table 3 summarizes the impact of alternative lags on the PM₁₀ variable using the basic logistic regression model for lower and upper respiratory symptoms for Odean Circle adults, nurses, and children. For Odean Circle adults, this model controls for

a subject's age, sex, educational level, having a chronic respiratory condition, having no air conditioning in the home, and daily average temperature. For the nurses, there was no variation in sex, education, or air conditioning, so these were not included in the model. For children, the model includes age, sex, having a chronic respiratory condition, having no air conditioning in the home, daily average temperature, and daily average humidity. Lags of up to 3 days and moving averages of up to 4 days (i.e., the average of the current day's PM₁₀ concentration and the concentrations on the three previous days) were examined in these basic models. For all three panels and both outcomes, a 4-day moving average generated the strongest associations with PM₁₀. However, positive associations were indicated for all of the lags examined, and statistically

significant results were obtained for all three moving average measures. Based on these results, the 4-day moving average was selected as the basic measure of PM₁₀ for subsequent sensitivity analyses.

All the individual characteristics shown in Table 1 were included in preliminary analyses, but only those with statistically significant relationships with symptoms were retained in the basic model. Having a household member who smokes (none of the subjects smoked) or using charcoal for cooking were not significant for the adults or for children, except for upper respiratory symptoms in children, which showed a higher frequency for those who had a smoker in the house. However, the PM₁₀ coefficient for upper respiratory symptoms in children was not changed when the household smoker variable was added to the model. Having no air conditioning had an unexpected negative sign on symptom frequencies in the children, but had the expected positive sign for adults. The result for children may have been due to correlation with socioeconomic status rather than an actual beneficial respiratory effect of having no air conditioning.

Those with a chronic respiratory condition were much more likely to have symptoms, but interactions with the PM₁₀ variable were not statistically significant, suggesting those with a chronic respiratory condition were no more likely to be affected by daily fluctuations in PM₁₀ than those without a chronic condition. Interactions between PM₁₀ and other variables, including no air conditioning and presence of household smoker, were also tested and none were found to be statistically significant. It is important to note these are simple binary variables for each subject and do not reflect the potential impact of day-to-day fluctuations in such exposures or differences in the amount of exposure for subjects who are exposed. These findings, therefore, suggest only those exposed to environmental tobacco smoke or to charcoal smoke in the home show no evidence of a different reaction to fluctuations in daily concentrations of outdoor PM₁₀. They should not be interpreted as showing no effect of these indoor exposures on daily symptoms, because they were not measured as daily exposures.

The PM₁₀ effects in the basic model and sensitivity analyses are summarized in Table 4. First, the results for the basic model are reported with and without a variable controlling for the impact of daily average temperature (unlagged). Adding temperature to the model attenuated the effect of PM₁₀ somewhat for the adult panels, but caused a slight increase in the estimated PM₁₀ effect for children. Temperature was negatively associated with symptoms (i.e., fewer symptoms were reported on hotter days). For Odean Circle

Table 3. Logistic regression PM₁₀ coefficients (standard errors) $\times 100$ for alternative lags and moving averages.

PM ₁₀ lag or moving average	Lower respiratory symptoms			Upper respiratory symptoms		
	Odean Circle adults ^a	Nurses ^b	Children ^c	Odean Circle adults ^a	Nurses ^b	Children ^c
Same day	0.59*** (0.08)	0.20* (0.09)	0.41*** (0.10)	0.78*** (0.08)	0.23* (0.09)	0.37** (0.10)
Lag 1 day	0.46*** (0.08)	0.16 (0.09)	0.35*** (0.09)	0.61*** (0.08)	0.26** (0.09)	0.36*** (0.09)
Lag 2 days	0.48*** (0.08)	0.14 (0.09)	0.20* (0.08)	0.61*** (0.08)	0.27** (0.09)	0.31*** (0.08)
Lag 3 days	0.41*** (0.08)	0.11 (0.09)	0.11 (0.08)	0.52*** (0.08)	0.26** (0.09)	0.19* (0.08)
2-Day moving average	0.65*** (0.09)	0.20* (0.10)	0.48*** (0.11)	0.85*** (0.09)	0.29** (0.10)	0.46*** (0.11)
3-Day moving average	0.79*** (0.10)	0.23* (0.11)	0.52*** (0.11)	1.05*** (0.10)	0.37*** (0.11)	0.55*** (0.11)
4-Day moving average	0.89*** (0.11)	0.27* (0.12)	0.56*** (0.12)	1.14*** (0.11)	0.45*** (0.12)	0.61*** (0.12)

^aOdean Circle adults model includes daily average temperature (same day), age, sex, educational level, having a chronic respiratory condition, and having no air conditioning in the home. ^bNurses model includes daily average temperature (same day), age, and having a chronic respiratory condition. ^cSchoolchildren model includes daily average temperature (same day), daily average humidity (same day), age, sex, having a chronic respiratory condition, and having no air conditioning in the home.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 4. Basic model and sensitivity analysis results (odds ratios and 95% CIs for 45 $\mu\text{g}/\text{m}^3$ change in PM₁₀).

Model ^a	Lower respiratory			Upper respiratory		
	Odean Circle adults	Nurses	Children	Odean Circle adults	Nurses	Children
Basic model without weather variables	1.66 (1.52–1.82)	1.22 (1.10–1.36)	1.22 (1.11–1.35)	1.94 (1.77–2.12)	1.35 (1.22–1.48)	1.31 (1.19–1.44)
Basic model with weather variables	1.49 (1.35–1.64)	1.13 (1.02–1.26)	1.29 (1.16–1.43)	1.67 (1.52–1.84)	1.22 (1.10–1.36)	1.32 (1.18–1.46)
Add symptom yesterday	1.51 (1.37–1.67)	1.12 (1.01–1.25)	1.26 (1.14–1.40)	1.38 (1.24–1.53)	1.11 (0.98–1.27)	1.14 (0.97–1.34)
Omit high (25%) temperature days	1.56 (1.38–1.77)	1.22 (1.08–1.38)	1.66 (1.40–1.96)	1.56 (1.38–1.77)	1.26 (1.12–1.43)	1.53 (1.30–1.81)
Omit low (25%) temperature days	1.38 (1.23–1.54)	1.12 (0.98–1.28)	1.15 (1.03–1.29)	1.51 (1.33–1.70)	1.17 (1.03–1.32)	1.21 (1.08–1.36)
Limit to new symptom days	1.43 (1.24–1.65)	1.27 (1.05–1.54)	1.08 (0.87–1.33)	1.56 (1.36–1.80)	1.31 (1.09–1.58)	0.99 (0.78–1.25)
Fixed-effects model ^b	1.53 (1.36–1.71)	1.10 (0.98–1.24)	1.13 (1.05–1.23)	1.69 (1.49–1.91)	1.19 (1.05–1.34)	1.10 (1.02–1.18)

^aThe PM₁₀ measure in all models is the 4-day moving average. Other independent variables include daily temperature (same day), age, sex, educational level, having a current chronic respiratory condition, and having no air conditioning in the home, as appropriate (see Table 3). The models in the sensitivity analyses include daily temperature. The children's model also includes same day humidity. The 45 $\mu\text{g}/\text{m}^3$ increment in PM₁₀ approximates the interquartile range. ^bThe fixed-effects models include the daily weather variables.

adults, for an interquartile change (75th–25th percentile) in PM₁₀ of approximately 45 µg/m³, the odds ratio is 1.66 [95% confidence interval (CI) = 1.52–1.82] for lower respiratory symptoms and 1.94 (95% CI = 1.77–2.12) for upper respiratory symptoms. Lower effect magnitudes were observed for the panels of nurses and children, but PM₁₀ was associated with statistically significant increases in frequencies for both symptom categories for all three panels, with and without daily weather variables included in the models.

The inclusion of a variable indicating the presence of a symptom on the prior day caused virtually no change in the estimated PM₁₀ effects for lower respiratory symptoms for all three panels relative to the basic model with daily weather variables, but attenuated the estimated effect of PM₁₀ on upper respiratory symptoms in all three panels. Omitting the hottest 25% of the days tended to increase the estimated association, whereas omitting the coldest 25% of the days lowered the estimate, but the PM₁₀ effect remained statistically significant in nearly all cases. The effects of PM₁₀ on the likelihood of a new symptom episode were examined in an analysis that included only those days for which there were no symptoms reported on the previous day. The results indicate an association exists for both adult panels and for both outcomes. The magnitude and statistical significance of the PM₁₀ effect remained comparable to that found in the original model for all days. However, the results for children showed no statistically significant effect of PM₁₀ on new symptoms. We also ran a model in which cough was not included as a lower respiratory symptom. The results were similar to those obtained for lower respiratory symptoms when cough was included.

The last row in Table 4 shows the PM₁₀ results estimated with a fixed-effects model that included the daily weather variables. The fixed-effects model allows the baseline symptom incidence to vary for each individual and corrects for the correlations among repeated responses from the same individuals. The PM₁₀ results for the fixed-effects models for the two adult panels were little changed from the results using the basic model with daily weather variables. However, the PM₁₀ results for the children were about 50% lower, but still statistically significant. Overall, the central estimate for the odds ratios for a 45 µg/m³ change in PM₁₀ calculated from the sensitivity test results for the Odean Circle adults ranges from 1.38 to 1.66 for lower respiratory symptoms and from 1.38 to 1.94 for upper respiratory symptoms. For the nurses the central odds ratios from the sensitivity tests range from 1.10 to 1.27 for lower respiratory symptoms and from 1.11 to 1.35 for upper respiratory

symptoms. For children the odds ratio for probability of a symptom day ranges from 1.08 to 1.66 for lower respiratory symptoms and from 0.99 to 1.53 for upper respiratory symptoms. No association was found for asthma episodes, but these were infrequent in the data.

Table 5 shows the results of two alternative assumptions that give the likely highest and lowest PM₁₀ effects and reflect alternative approaches of accounting for time trends in the data (Figure 1). The first specification includes age, sex, educational level, having a chronic respiratory condition, and having no air conditioning in the home, but does not include any terms for time and temperature (which generally increased over time). This model reflects the hypothesis that the decreasing trend in symptoms is entirely attributable to the decreasing trend in PM₁₀ concentrations during the study period. At the other extreme, loess smoothers of symptoms over both time and temperature are added to the model. The smooth of symptoms over time causes a significant attenuation in the estimated odds ratio for PM₁₀ for all three of the panels. In this model the downward trend in symptoms is captured by the smooth variable, essentially implying only a small portion of the downward trend is attributable to decreasing concentrations of PM₁₀. It is notable that even with this extreme assumption, a statistically significant association between symptoms and PM₁₀ is still observed for the Odean Circle adult panel.

Dichotomous samplers located at Odean Circle and at Chulalongkorn Hospital during part of the study period provided a limited number of days of PM_{2.5} concentrations. We

therefore estimated a PM_{2.5} coefficient and a PM₁₀ coefficient for the same days to compare their associations with symptoms. As summarized in Table 6, statistically significant associations were found between respiratory symptoms and both PM₁₀ and PM_{2.5}, measured as 4-day moving averages, for both adult panels. The odds ratios for interquartile ranges (45 µg/m³ for PM₁₀ and 26 µg/m³ for PM_{2.5}) are comparable in magnitude for all the comparisons. For children, however, the PM_{2.5} results are not statistically significant.

Discussion

Taking the results of the three panels together, there is evidence of an association between upper and lower respiratory symptoms and PM₁₀. Replicating previous studies from the Western industrialized cities in a city such as Bangkok, which has very different meteorologic conditions, baseline health status, and activity patterns, provides strong evidence for causality.

The results of the daily symptom diaries for adults in the Odean Circle area show substantial and robust PM₁₀ effects on the incidence of upper and lower respiratory symptoms. One of the selection criteria for this subject group was that they worked in shops not air conditioned in a high-traffic commercial area. This group, therefore, is expected to have fairly high exposures to outdoor air pollution during the day. Positive associations of smaller magnitude were also found between PM₁₀ and symptoms for nurses working and living at Chulalongkorn Hospital. The nurses were expected to have lower exposures to outdoor air pollution because they worked primarily

Table 5. Alternative treatment of time trends (odds ratios and 95% CIs for 45 µg/m³ change in PM₁₀).

Model ^a	Lower respiratory			Upper respiratory		
	Odean Circle adults	Nurses	Children	Odean Circle adults	Nurses	Children
Basic model with no weather variables	1.66 (1.52–1.82)	1.22 (1.10–1.36)	1.22 (1.11–1.35)	1.94 (1.77–2.12)	1.35 (1.22–1.48)	1.31 (1.19–1.44)
Above with smoothers for symptoms and temperature	1.20 (1.08–1.34)	1.06 (0.95–1.18)	1.01 (0.90–1.15)	1.19 (1.07–1.32)	1.03 (0.97–1.10)	1.12 (1.01–1.25)

^aThe PM₁₀ measure in all models is the 4-day moving average. Other independent variables include age, sex, educational level, having a chronic respiratory condition, and having no air conditioning in the home, as appropriate for each panel (Table 3). The 45 µg/m³ increment in PM₁₀ approximates the interquartile range.

Table 6. Comparative results of PM₁₀ and PM_{2.5} using the dichotomous sampler data (odds ratios and 95% CIs for interquartile ranges).

PM measure ^a	Lower respiratory			Upper respiratory		
	Odean Circle adults	Nurses	Children	Odean Circle adults	Nurses	Children
PM ₁₀ dichotomous sampler	1.55 (1.32–1.81) <i>n</i> = 45	1.15 (0.99–1.34) <i>n</i> = 34	1.20 (1.03–1.39) <i>n</i> = 34	1.68 (1.43–1.97) <i>n</i> = 45	1.19 (1.03–1.38) <i>n</i> = 34	1.15 (0.99–1.34) <i>n</i> = 34
PM _{2.5} dichotomous sampler	1.48 (1.29–1.69) <i>n</i> = 45	1.16 (1.02–1.32) <i>n</i> = 34	1.11 (0.96–1.29) <i>n</i> = 34	1.66 (1.44–1.90) <i>n</i> = 45	1.23 (1.08–1.40) <i>n</i> = 34	1.13 (0.97–1.31) <i>n</i> = 34

^aThe PM₁₀ and PM_{2.5} measures in all models is the 4-day moving average. Other independent variables include age, sex, educational level, having a chronic respiratory condition, and having no air conditioning in the home, as appropriate for each panel (Table 3). The interquartile range for PM₁₀ is 45 µg/m³, and the interquartile range for PM_{2.5} is 26 µg/m³.

in air-conditioned areas of the hospital. Finally, positive associations were also observed in the panel of schoolchildren. Based on the basic model specifications, including daily weather variables, the estimated PM₁₀ effect for the schoolchildren was somewhat larger than for the nurses, but smaller than for the Odean Circle adults. The results for schoolchildren were not as robust to variations in the model specifications as those for the adult panels. This may be because the diary was conducted for fewer days with the children and children may not report their symptoms as accurately as adults.

PM also was associated with the initiation of a respiratory symptom episode (i.e., the likelihood of a day with symptoms when there were no symptoms on the previous day) for both upper and lower respiratory symptoms in both of the adult panels, with odds ratios comparable to those found for all symptom days. The results for new symptoms for the schoolchildren, however, were not statistically significant. This suggests serial correlation may be more problematic in the data for the children than for the adults. The magnitude of the effect for children was also less in the fixed-effects model, indicating correlation in the responses for a given child and the nonindependence of the responses.

The diary was conducted during the high-pollution months in Bangkok (December through March) and is not necessarily representative of the effects of PM₁₀ during other times of the year or for other populations, although there is no reason to expect PM₁₀ effects occur only during high-pollution months. Table 7 shows results from some comparable panel studies in the United States. For adults the estimated odds ratios in Bangkok are higher than the findings of a previous study undertaken in Los Angeles, California, USA. It is also of note that the incidence of adult symptoms is much higher in Bangkok than in studies in the United States. This may be because of differences in reporting or in definitions of

symptoms, or because of real differences in respiratory symptom incidence. Regardless of the reason for the difference, it means that even if the odds ratios in Bangkok and the West were similar, the absolute increase in symptoms for a unit change in PM₁₀ would be substantially greater in Bangkok.

The results for children in Bangkok are comparable to the results for children in the Utah study (10) and are somewhat lower than the results for children in the six-city study in the United States (11). The average symptom incidence from the six-city study was not reported, however, so it is difficult to interpret this comparison. The symptom incidence was quite a bit lower in the Utah study than in the Bangkok study.

Measurement error in air pollution epidemiology is always of concern. During this study there was a high daily correlation ($r > 0.9$) of two monitors, one roadside and one off-street, located at Chulalongkorn Hospital. In addition, the daily correlation of the beta-gauge monitors at Chulalongkorn with that at Odean Circle was very high ($r > 0.9$). These data support the concept of a citywide exposure to PM₁₀ that fluctuates concurrently throughout the area. Nevertheless, it is likely that significant hot spots also exist within the metropolitan area.

The PM_{2.5} measurements are of interest because of the limited monitoring to date of this pollutant. The averages of the daily ratios of measured concentrations of PM_{2.5} to PM₁₀ based on the dichotomous sampler measurements at Odean Circle and Chulalongkorn Hospital are 53 and 50%, respectively. This is comparable to the ratios measured in cities in the Western United States and somewhat lower than is typical in cities in the Eastern United States (12,13). The data also indicate a high correlation between daily concentrations of these pollutants at both locations. At Chulalongkorn the correlation coefficient between daily PM₁₀ and PM_{2.5} was 0.92; at Odean the correlation coefficient was 0.85. This indicates the day-to-day variation in PM_{2.5}

tracked very closely with that of PM₁₀. The results suggest associations between an interquartile change in PM_{2.5} and both lower and upper respiratory symptoms in the two adult panels comparable in magnitude to the associations seen with an interquartile change in PM₁₀. High correlations between the two measures and the limited number of days for which both measures were available make it difficult to say which measure is more closely associated with respiratory symptoms. However, because PM_{2.5} results primarily from fuel combustion, it seems likely combustion-related PM₁₀ is a major, if not primary, causative constituent associated with respiratory symptoms in the Bangkok population.

The analysis indicated when temperature was added to the models for the adults, the estimated effect of PM₁₀ was slightly attenuated. This may be due to the correlation between temperature and PM₁₀ ($r = -0.38$). Temperature is inversely associated with symptoms, indicating symptoms were less frequent as the study moved into the hotter period of March. It is possible the frequency of respiratory symptoms is higher during the winter. However, winter temperatures are not as cold in Bangkok as they are in temperate climates, where respiratory symptoms are notably more frequent during winter months. Specifically, the 24-hr average temperature in the winter months in Bangkok is typically in the high 70s or low 80s (°F). Therefore, the most likely explanation for the inverse association between temperatures and symptoms is that in Bangkok, extremely high temperatures and humidity that typically begin in March may trigger changes in behavior, such as spending more time indoors and reducing activity. Thus, during the very warm period at the end of the panel study, the drop in symptom reporting may be due to lower air pollution; higher temperature, decreased time outdoors, and lower exposures; or lower reporting owing to diminished attention to diary compliance. It is unlikely the higher temperatures per se are causally associated with decreases in symptoms.

Adding a smoother variable representing the underlying pattern of symptom frequencies over time to the model also reduced the estimated effect of PM₁₀. This smooth is similar to adding a day-of-study variable, but allows for more variability in how the symptom frequencies vary over time. Although smoothers are very useful at capturing seasonal patterns that the analyst wishes to control for in multiple-year data, they are not always as helpful with short-term data such as these. The problem is the smooth may capture some of the variation in the outcome associated with other time-dependent variables such as air pollution

Table 7. Comparison of results from daily respiratory symptom diary studies.

First author (reference)	Location	Age group	Symptom category	Average symptom incidence	Estimated OR for 45 µg/m ³ PM ₁₀ (95% CI)
Ostro et al. (9)	Los Angeles	Adults	Lower respiratory	1.5%	1.19 ^a (1.06–1.34)
This study	Bangkok	Adults	Lower respiratory	25%	1.49 (1.35–1.64)
This study	Bangkok	Adults	Upper respiratory	24%	1.67 (1.52–1.84)
Schwartz et al. (10)	6 U.S. cities	Children	Lower respiratory	Not reported	1.89 (1.31–2.72)
Schwartz et al. (10)	6 U.S. cities	Children	Upper respiratory	Not reported	1.35 (0.97–1.87)
Pope et al. (11)	Utah valley	Children	Lower respiratory	16%	1.25 (1.05–1.49)
Pope et al. (11)	Utah valley	Children	Upper respiratory	34%	1.18 (1.03–1.34)
This study	Bangkok	Children	Lower respiratory	59%	1.29 (1.16–1.43)
This study	Bangkok	Children	Upper respiratory	53%	1.32 (1.18–1.46)

OR, odds ratio.

^aThese results were estimated in the original study for sulfate aerosols and are adjusted here to an approximate equivalent change of 45 µg/m³ PM₁₀ assuming a sulfate to PM₁₀ ratio of 0.15 in Los Angeles.

REFERENCES AND NOTES

concentrations. It is notable then that even with a smooth of time in the model, an association between PM_{10} and both symptom categories remains statistically significant for the Odean Circle adults as well as for the children for upper respiratory symptoms. We expect these groups have higher exposure to outdoor pollutants than the nurses because they spend less time in air-conditioned buildings. We give greater weight to the results without the smooth of time variable because there appears to be a good chance the smooth is capturing some of the real effect of the decline in PM_{10} concentrations during the study period and thus causing the PM_{10} coefficient to understate the true effect of PM_{10} on respiratory symptoms. However, the uncertainty about how to interpret the results when the smooth of time is included cannot be fully resolved without running similar panel studies for longer periods of time and during different seasons.

It is difficult to identify any potentially confounding omitted factor that is correlated with both PM_{10} and frequencies of reported symptoms. It appears the decrease in symptom incidence over time was a real phenomenon and not due to response bias. Diary compliance was extremely high throughout

the study. In addition, for all three panels, symptoms decreased during the study period and daily symptom incidences were highly correlated across the three panels.

The results reported here show statistically significant PM_{10} effects in three different population groups in Bangkok, but these groups had some unique characteristics that make it difficult to generalize to the entire population of Bangkok. Daily symptom diary studies could be extended to other population groups whose exposure circumstances vary. Those who commute may have even higher exposures than the Odean Circle adults in this study because of their time spent in traffic. Others who work in air-conditioned offices and have air conditioning in their homes may have even less exposure than the nurses in this study. In addition, this symptom diary was completed during the high-pollution months. It would be useful to test for this association during other seasons and with other panels. For Bangkok and other cities outside of the industrialized West, further diary work would also be enhanced by obtaining daily information on indoor sources of PM, including exposure to cooking sources. In many countries, these sources represent a significant burden (13).

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